Evaluation of the equity of Bikeshare System accessibility: A case study of Chicago

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Option paper

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Abstract

Bikeshare is a new type of shared economy transportation mode which became popular in the U.S. in a short period of time. To ensure equal access to transportation system between groups with different social characteristics is an important aspect of social equity. This paper aims to identify if there are significant differences existing in demographic characteristics of people who live within 0.25 mile of bikeshare stations. Demographic characteristics include race, income level, education level, and language proficiency. The content includes a brief overview of history of bike share, current trend of bike share in the U.S., a case study of Divvybikes in Chicago, IL, and a brief introduction of spatial analysis process. A data analysis was then conducted on the demographic data of people living near Divvybikes stations in order to calculate the ratio of groups with different demographic characteristics who are more accessible to bike share. The ratio was used to determine if there is adverse impact on vulnerable groups based on The 80% Rule. Several spatial analysis maps revealing spatial autocorrelation of equity and hotspots of inequity were created by calculating Moran's I and Getis-ord Gi index. Finally, limitations and recommendations for the equity of bike share system accessibility are provided.

The results indicate that at least 33 percent of stations' ratios are below 0.8 for all demographic characteristics categories, except for gender, which means that inequity of bikeshare system accessibility between exists.

Key words: bike share, social equity

Literature review

Bike share

Bike share refers to the service in which bikes are made available on campus, near subway stations, bus stops, residential areas, commercial areas, and public service areas, to individuals for use on a short time basis (Pedestrian and Bicycle Information Center, 2018). Bike share programs are a new type of transportation rental business, most of which charge users based on the time of use. Some programs provide subscription options that allow users to use shared bikes for free for the first hour, or unlimited usage with a monthly or annual membership (Parkes, Marsten, Shaheen, 2013).

Users can rent shared bikes from bike stations, whose location information can be found on the mobile applications provided by bike share operators. Usually bikes are locked into docks, which are similar to bike racks. Users can use mobile applications to locate the nearest bike station that has available bikes and unlock the bike from the dock using phone's Bluetooth. When finished, users can return the bike to the nearest bike station that belongs to the same program and end the trip (On bike share, 2018). There is also dockless bike share which, as its name suggests, doesn't have a docking station to store bikes.

The "last mile" , which refers to the distance between public transit stations and riders home, has always been a challenge faced by many urban transportation systems, especially in mega cities, such as New York, London, and Beijing. Bike travel is seen as an efficient way to solve the "last mile" problem (Liu, 2016). Bike share systems can provide additional transportation needs, point-to-point transportation, or extensions of public transport networks. The lack of bike travel in the urban transportation system enables bike share programs to make full use of the rapid

economic development of the city. Furthermore, bike share programs can maximize the use of the road space to alleviate traffic congestion.

Bike share is also a new type of environmentally friendly shared economy since it is in line with the concept of low carbon travel. According to a report prepared by JCDecaux, compared to the automobiles, bike travel can reduce 200 g Carbon Dioxide emissions per kilometer on average (JCDecaux, 2017). In addition, share bikes can play a vital role in improving public health by encouraging more physical activities. This new type of transportation model has attracted more and more public and government attention. As the bike share trend takes off, governments have actively participated in establishing related regulation (South Chinese Morning Post, 2017).

The history of bike share

The bike share program can be traced back to 1960s in Europe. The group, Provo, launched White Bikes in Amsterdam and put fifty unlocked bikes for the public to use freely. This first generation of bike share soon failed due to the fact that users stole and damaged the bikes (Shaheen & Guzman, 2011).

The second generation of bike share appeared in Copenhagen, which is known as the coin-deposit system, which brought in docking stations so that shared bikes could be locked. The safety of the bike was further enhanced by the University of Portsmouth, UK, who started the Bikeabout scheme and brought in the new technology to the bike share program. Users needed a "smart card" which was used to unlock bikes from bike docks and record bike usage. CCTV cameras were also installed at bike stations to limit vandalism (Black, Faber, Potter, 1998).

Based on previous experience, the third generation bike share was armed with information technology (IT). The most innovative component was the introduction of the mobile application

that allowed users to locate bike stations, reserve bikes, track routes, and pay for fees. Vélo à la Carte was launched in 1998 in Rennes, France, which was the first IT-based system. Today, the most widely known IT-based system is Vélib' in Paris, which has 20,600 bikes and 1,451 bike stations (Shaheen & Guzman, 2011). Recently, with the invention of the electric vehicle, electric bikes have been put into use.

Worldwide trend of bike share

With more and more mature operation system, bike share becomes more and more popular worldwide. Today, most of bike share programs are fourth-generation system, which adds demand-responsive and multi-modal systems to third-generation system (Shaheen, Cohen, Martin, 2012). In May 2011, there were around 375 bike share systems, with 236,000 shared bikes (Midgley, 2013). And by April 2013, there were 517,000 shared bikes, and the number was doubled in two years. Figure 1 shows the global growth of bike share between 2000 to 2013, and the total number is still increasing. Bike share is ranked as the number one urban transportation mode with the most growth in the past 15 years.

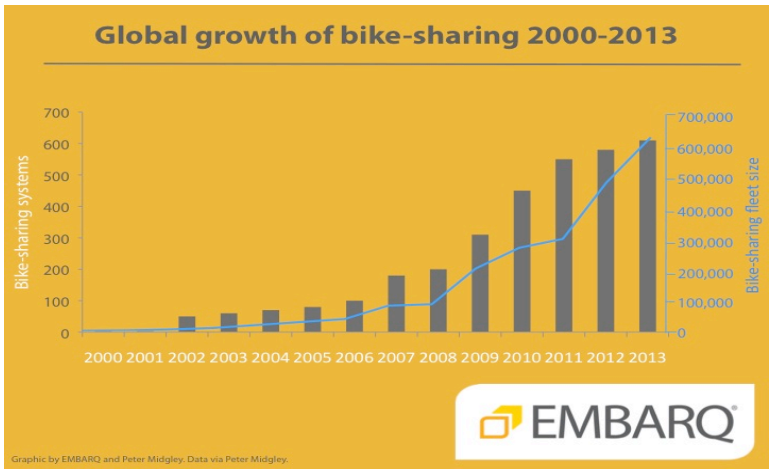


Figure 1. Global growth of bike-sharing 2000-2013 (Midgley, 2013)

Figure 2 shows that bike share has made a global expansion. There are about 639 bicycle-sharing schemes operating in 53 countries covering almost every region of the world (Midgley, 2013). This is especially the case in Asia. A number of bike share

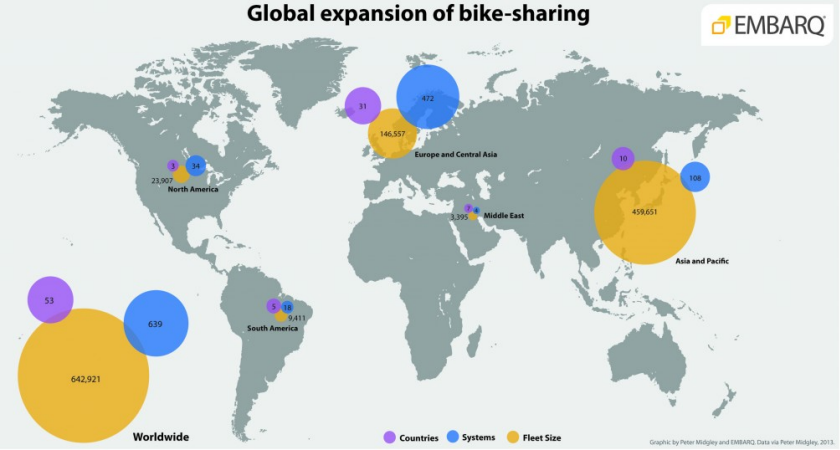


Figure 2. Global expansion of bike-sharing (Midgley, 2013)

programs were launched across China, with the biggest ones being in Wuhan and Hangzhou. Dockless bike share is the most common type in China, which can provide users maximum convenience to check in and return shared bikes. Ofo and Mobike are two of largest operators of bike share in Chinese market, and they also have business overseas. Ofo operates 100,000 dockless bikes in each of the cities of Shanghai, Beijing, Shenzhen and Guangzhou (Mead, 2017). Local governments in China encourage the development of bike share and offer financial incentives to the operators. Meanwhile, governments also publish and modify regulations to consisting with the rapid development of bike share market. The popularity of bike share in China leads to reduction in vehicle trips with less than five kilometers, which is good for reducing air pollution (Liu, Li, Deng, 2017). A report from the Transport Commission of Shenzhen suggests that more than 500,000 bike-share units had resulted in nearly 10 percent decrease of by private car travel and 13 percent of gasoline consumption (Reuters, 2017).

Although China has the largest number of bike share system for single country, majority of bike share programs are in Europe, where bike share was first introduced into market. Paris's Vélib is the second-largest bike share operator in the world, which has 1,205 stations and nearly 20,000 bikes in France. Users of Vélib made 86,000 trips per day on average (Pacheco, 2015). Vélib is also the most innovative bike share operator in the world, which actively introduced hi-tech components into their bike share program, such as electric shared bikes. In June 2014, they launched P'tit Vélib, which is an initiative providing bikes to children. Vélib is also one of the supporters of recommending cyclists to wear helmets to enhance safety.

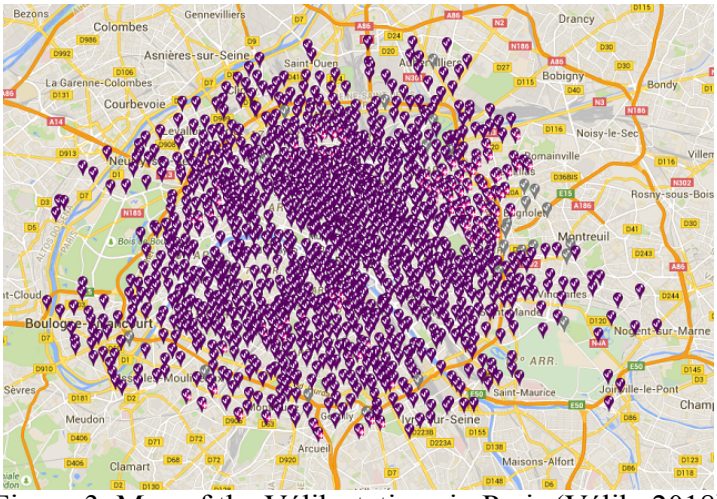


Figure 3. Map of the Vélib stations in Paris (Vélib, 2018)

Since September 2017, dockless bike share began to penetrate into the Europe market, which can be found in variety of cities and total number keeps increasing. OBike, a Singaporean bike share operator, and Ofo, a Chinese bike share operator, are major foreign competitors and both have launched their operating programs in Vienna, Brussels, Prague, Paris, Munich, Frankfurt, Berlin, Milan, Rome, Rotterdam, Madrid, London, and many other major European cities (European Bicycle Manufacturing Association, 2018).

North America is a relatively new market for bike share. BIXI is the largest bike share system in Canada with over 5000 bicycles at 450 stations, located at Montreal, Ottawa, and

Toronto (Radio Canada, 2013). Vancouver started bike share program in the city in 2016 and the total number of shared bike achieved 2500 in 2017 (Mobi, 2018).

Brazil is also successful in bike share programs. For example, Brasília and Sao Paulo boast the two largest programs, with 400 and 285 stations respectively. The total number of shared bike trip made in Rio de Janeiro is 6.2 million within 4 years (Fisherman, 2015).

Bike share in the U.S.

According to a report published by the National Association of City Transportation Officials (NACTO, 2017), the total number of shared bike rides in the United States has exceeded 88 million since 2010. In 2016, the number of rides exceeded 28 million, which is equal to the annual number of rides with the Amtrak system. Figure 4 shows the bike share ridership between 2010 to 2016, and five biggest bike share programs in the U.S. (Citi Bike in New York, Capital Bikeshare in Greater Washington DC, Citi Bike in Miami, Divvy in Chicago, and Hubway in Greater Boston) contributed 85% of all trips.

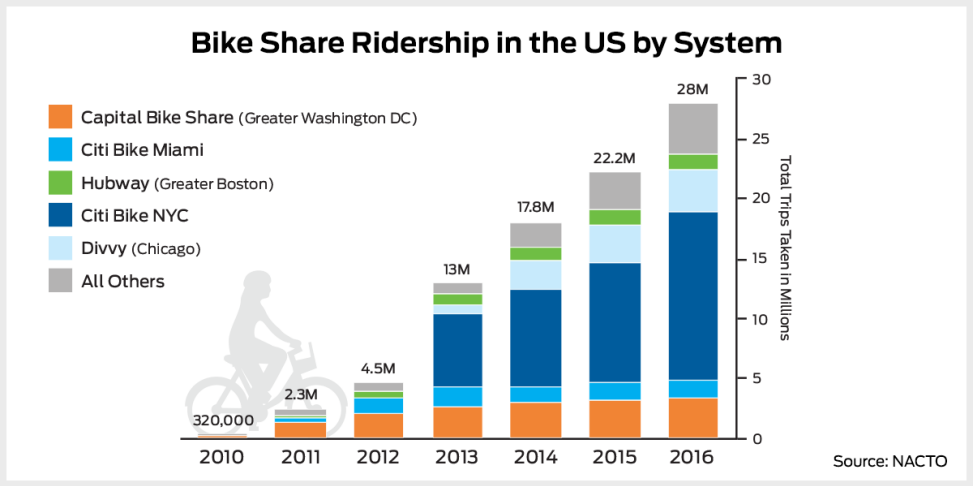


Figure 4. Bike share ridership in the US by system (NACTO, 2017)

The first bike share system in the United States was officially launched in 2010. At that time, only 1600 bikes were shared in the United States. In 2013, the growth of bike share program started and the number of shared bike quickly increased from 7,400 bikes in 2012 to 19,900 bikes in 2013, and further increased to 42,000 bikes in 2016 (NACTO, 2017). Currently, the number of bike share systems in the United States (at least 10 stations and 100 bicycles open to the public) has been increasing year by year. In 2010, there were only four shared bicycle systems in the United States, and by the end of 2016, it had increased to 55, including 80% of the shared bicycle systems have been operating for more than 1 year (NACTO, 2017).

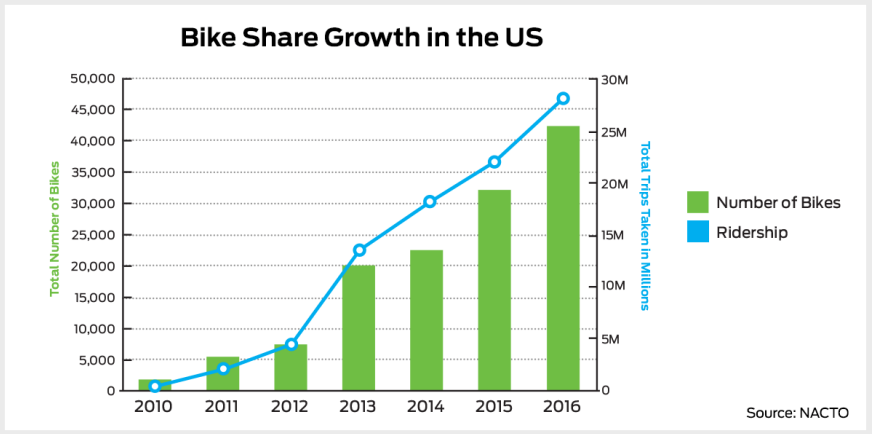


Figure 5. Bike share growth in the US (NACTO, 2017)

Although the scale of bike share continues to expand, the time for a single shared bike ride still remains very short. For those users who have membership, the average ride duration is only 12 minutes, while for casual users, the average ride duration is 25 minutes (NACTO, 2017).

Next step for bike share in the U.S.

As the figures suggest above, the bike share market in the U.S. has a trend of increasing. For example, New York's Citi Bike is adding another 2,000 bikes; Houston is trying to make size to over 100 stations; and the San Francisco Bay Area Ford GoBike is expanding from a 700 to a 7,000 bike system ((NACTO, 2017). What's more, more cities begin to test dockless shared bikes which is transformed from Chinese market. Seattle became the first U.S. city that allowed dockless shared bikes to be put into use in the city, which made a surprisingly success. The new system generated more than 15,000 rides in the first week after it was launched (Margolis, 2017). Washington D.C. installed four dockless bike share systems (Heining, 2017). Another trend shown in the U.S. bike share market is that more foreign investment appeared. Chinese bike share operator Ofo is projecting to cover 100 US cities in 2018.

Dockless shared bikes also received some pushbacks from some cities' governments based on the lessons learned from China and Europe. European cities are overwhelmed by dockless bike share mode, and some of local governments published regulations to prevent dockless shared bikes from further causing chaos in public space due to the lack of bike placement regulations. In January 2018, National American Bikeshare Association (NABSA) published Dockless Bikeshare Regulation Preliminary Guidance to help cities consider their needs and guide them in the elements to include in dockless bikeshare regulation (NABSA, 2018).

Equity concerns of bikeshare system

Transportation is a key component in everyone's daily life and transportation equity is consistent with the goals of the larger civil rights movement and the environmental justice movement (Bullard, 2003). Transportation equity is critical to address poverty, unemployment,

and equal opportunity goals and secure access to education, health care, and other public services for minority groups.

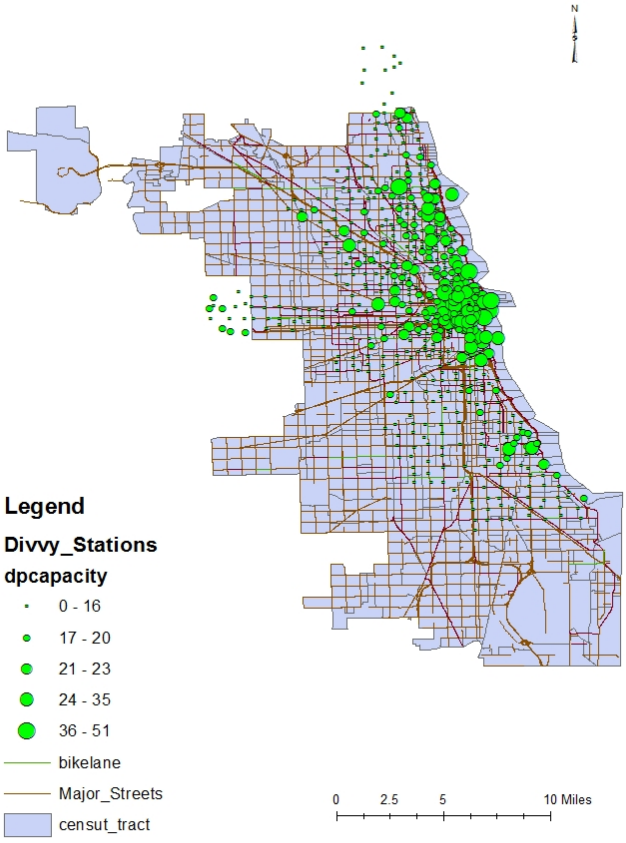
Six groups are considered as minority: racial minority, low income, less than high school education, linguistically isolated, under age 5, over age 64. Racial minority and low income are two major minority groups. Racial minorities are defined as everyone except for white non-Hispanics, and low income household is defined as household that has annual income up to twice the official poverty level. Linguistically isolated refers to households that all adults and teens have difficulty in speaking English. Those who are younger than 5 and those who are older than 64 are not applicable to be considered to evaluate the equity of bikeshare.

Disparate impact refers to "practices in employment, housing, and other areas that adversely affect one group of people of a protected characteristic more than another" in U.S. Labor Law. It is a violation of Title VII of the 1964 Civil Rights Act. There are multiple tests to prove if there is disparate impact existing. The 80% Rule was initially used to determine if company's hiring process has adverse impact on minorities. The method is to calculate the ratio of percentage of minorities applicants hired and percentage of non-minorities applicants hired, and compare the ratio to 80%. If the ratio is below 80%, it shows that there is adverse impact on minorities applicants (Biddle, 2006).

Case study

Chicago, IL is chosen as the most ideal case study to evaluate the equity of Bikeshare System access. The selection is made mainly based on the public data availability, the area's spatial shapefiles and demographic dataset availability, the operating status of the bike share systems, and the variable types being shared in the dataset.

Divvy is the bike share system operated by Motivate Inc. for the Chicago Department of Transportation The system was first launched on June 28, 2013, with 750 bikes at 75 stations open to the public initially. Now the size of the system expands to 5,800 bicycles at 580 stations and its daily ridership is more than 13,000 (City of Chicago, 2013). Figure 6 shows the location of the bike stations throughout the city and capacity of each station and Figure 7 shows the heat map of the Divvybike trip made in 2016.



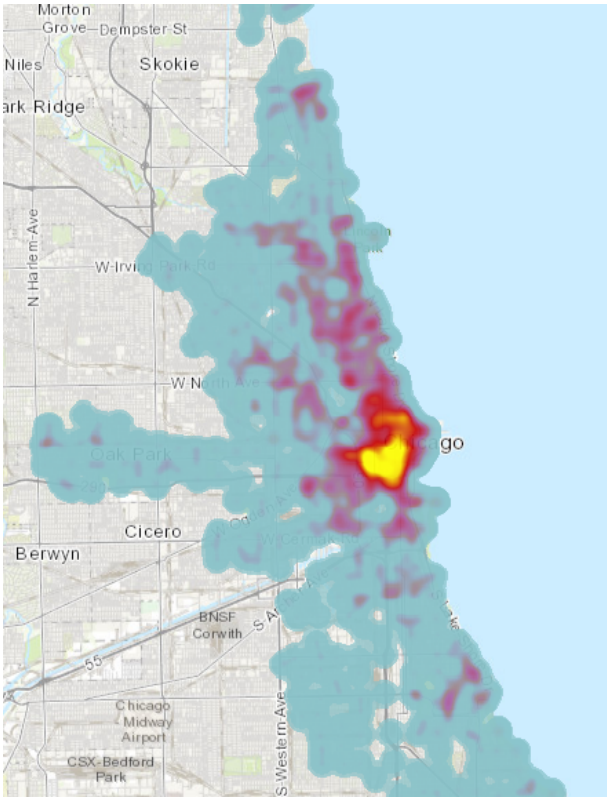


Figure 6 (left). Map of locations of the Divvybike station and its capacity

Figure 7 (Right). Distribution of trips of the Divvybike made in 2016

The single ride cost is $3 and daily pass is $15. Divvy also offers annual membership for a price of $99, which allows users enjoy first 45-minute of each trip for free. By 2015 the number

of annual membership achieves 31,000 (Divvybikes, 2016). Figure 7 and Figure 8 suggest that membership is the majority user type.

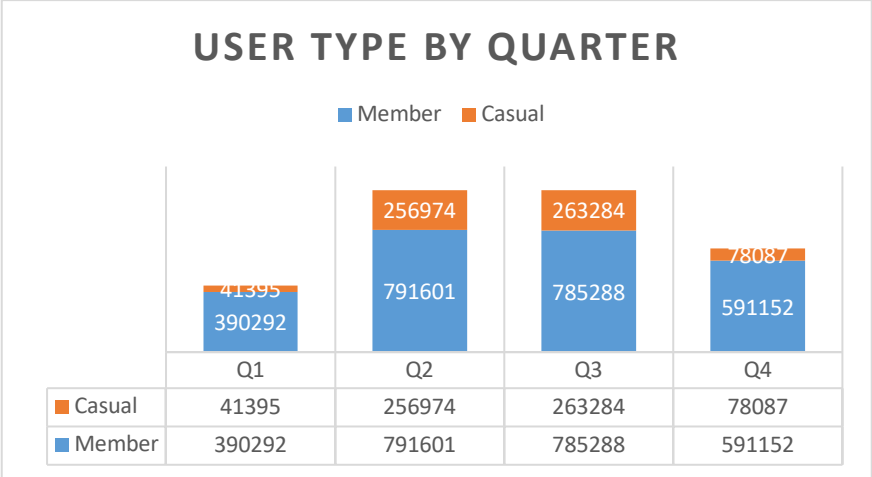


Figure 7. User type of Divvybike by quarter (Divvybike, 2016)

Divvy also has a close relationship with social media, including Tumblr and Instagram, where Divvy posts updates of information the newly-added bike stations and photos taken when they are riding Divvy shared bikes.

Methodology

Table 1 shows sources of data that will be used in the analysis.

Table 1. Data sources

Data	Source
2016 Divvybike Trip Data	divvybikes.com/data
2016 Divvybike Station Information	divvybikes.com/data
Census Tract and Block Group Shapefile	Chicago Data portal
Social Demographic Data	U.S. Census Bureau; Tiger/Line

This paper aims to identify if there are significant differences existing in demographic characteristics of people who live within 0.25 mile of bikeshare stations. The demographic

characteristic data is from 2016 American Community Survey 5-year file and variables selected to be included in the analysis are shown in table 2.

Table 2. Demographic characteristics selected in the analysis

Category	Variable
Race	White Population
	Non-White Population (Minority group)
Income level	Annual household income less than $49,999 (Low income group)
	Annual household income no less than $49,999
Gender	Male
	Female
Education Level	Less than high school
	No less than high school
Language proficiency	Linguistically isolated
	Not linguistically isolated

The 2016 Divvybike Station spreadsheet includes latitude and longitude information of each station so that station shapefile can be created in ArcGIS by using adding "Add XY Coordinates" tool. Then 0.25-mile buffers were created around each of the stations. Using buffer layer to intersect with block group layer, which stores demographic characteristics, can produce the new layer that has demographic data of people who live within 0.25 mile of each station. Since one station can service people who are from multiple block groups, each station's demographic data needs to be summarized to get the sum of each variable. The last step is exporting the result table to conduct data analysis.

Data Analysis

Data analysis is to identify the equity level of each station based on The 80% Rule. According to The 80% Rule, the ratios between minority groups and non-minority groups that live within 0.25 mile of each bike station need to be calculation, the equation is as follows:

$$\text{Ratio} = \frac{Number\ of\ minorities / Total\ number\ of\ minorities}{Number\ of\ non-minorities / Total\ number\ of\ non-minorities}$$

The summary of ratio results is shown in table 3.

Table 3. Summary of ratio results for each category of demographic characteristics

	<0.5	0.5-0.8	0.8-1	1-1.25	>1.25
Race	29%	14%	8%	8%	42%
Gender	1%	6%	38%	42%	13%
Education	25%	13%	6%	5%	50%
Language proficiency	41%	13%	7%	6%	33%
Income Level	15%	18%	13%	10%	44%

After ratios for each category of demographic characteristics being calculated, the graduated color quantities maps are created in ArcGIS, as shown in figures below:

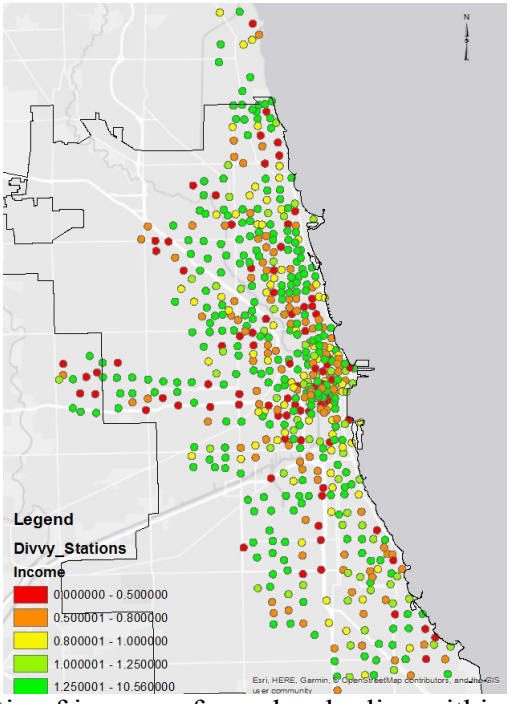
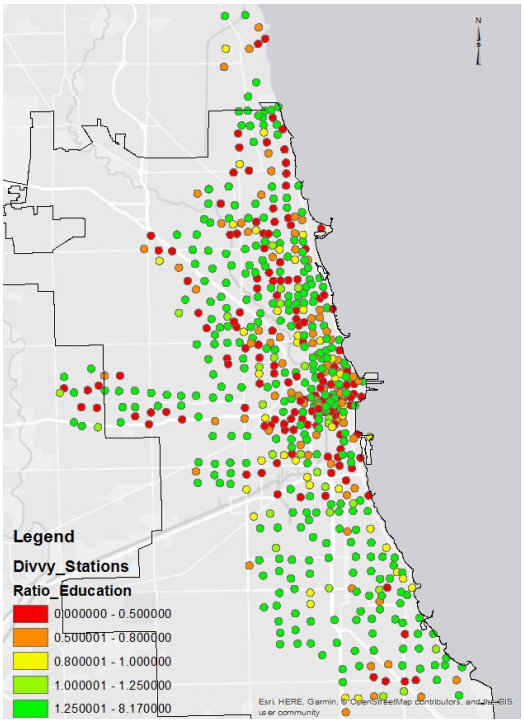


Figure 8. Map of equity ratio of income of people who live within 0.25 mile of station



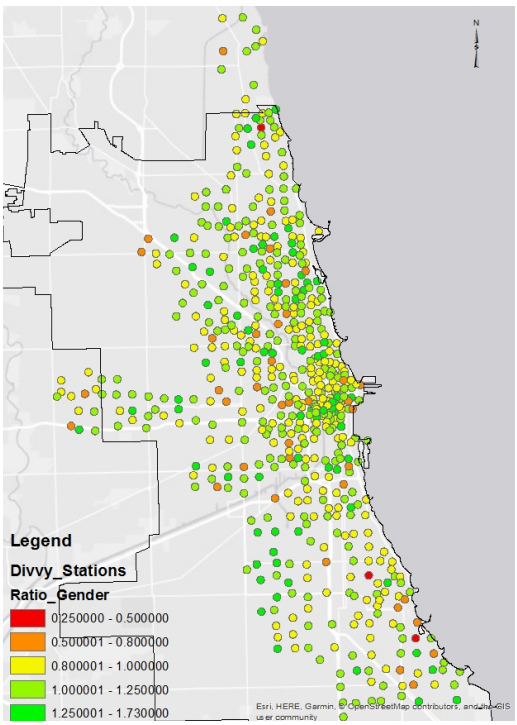
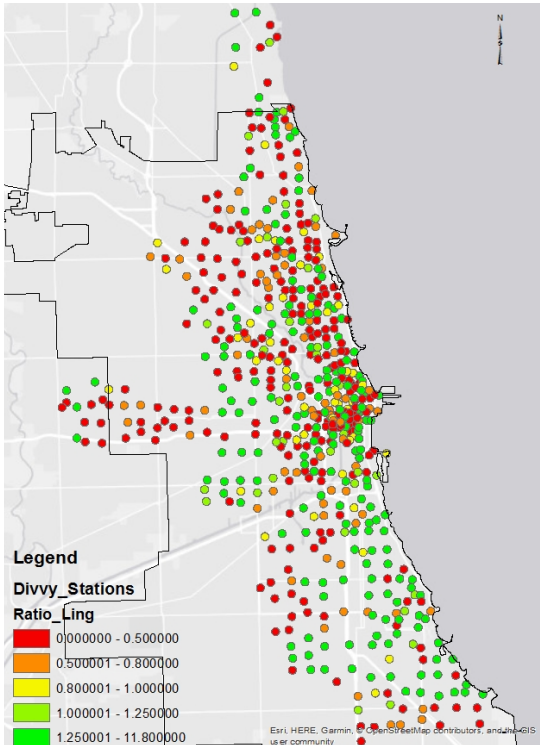


Figure 9 (left). Map of equity ratio of education of people who live within 0.25 mile of station
Figure 10 (right). Map of equity ratio of gender of people who live within 0.25 mile of station



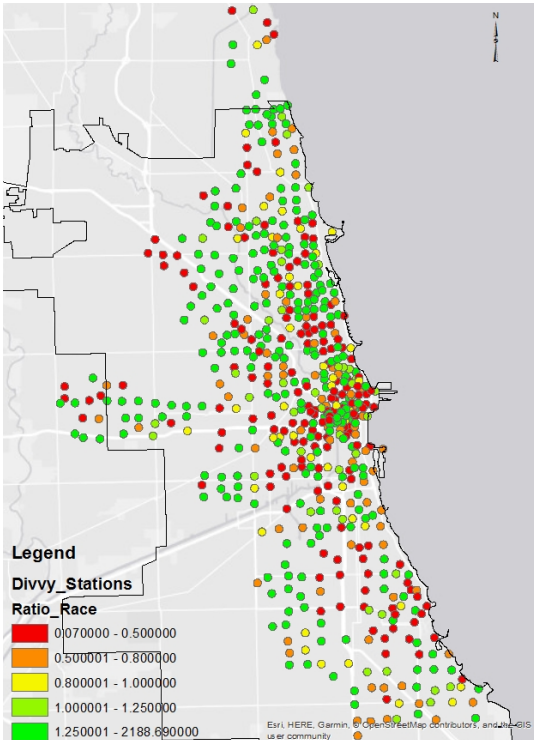


Figure 11 (left). Map of equity ratio of language proficiency of people who live within 0.25 mile of station
Figure 12 (right). Map of equity ratio of race of people who live within 0.25 mile of station

To identify if there is spatial autocorrelation existing, Moran'I is calculated for each category of demographic characteristics. Moran'I is the ratio of how alike of neighbor stations and how alike are all pairs of stations. It ranges from 1 to -1, and positives mean like tends to locate near like, while negatives mean like tends to locate near unlike. The result is shown in table 4.

Table 4 Result summary of Moran's I for each category of demographic characteristics

Category	Moran's Index	Variance	z-score	p-value
Race	0.009561	0.000216	0.770229	0.441164
Gender	0.005444	0.000346	0.387027	0.698736
Education	0.126068	0.000347	6.865502	0.000000
Language proficiency	0.031533	0.001019	1.042534	0.297164
Income	0.065317	0.001021	2.098693	0.035844

Based on the result of Moran's I, Getis-ord Gi analysis is conducted to identify hotspots of ratio of education of people who live within 0.25 mile of station, as shown in figure 13.

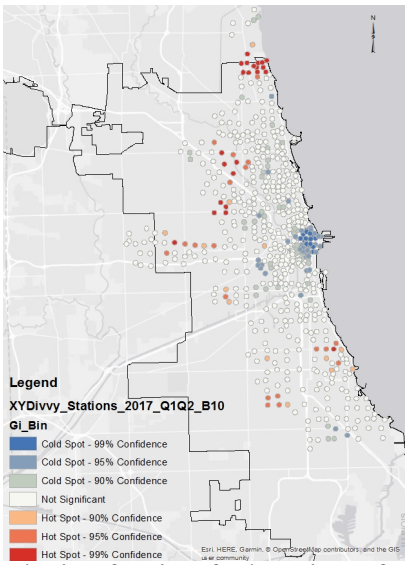


Figure 13. Map of hotspots analysis of ratio of education of people who live within 0.25 mile of station

Key Findings

By analyzing the results of equity of bikeshare system accessibility analyses, we report these key findings. First, ratios for each category of demographic characteristics of people who live within 0.25 mile of Divvy bike share stations are calculated. The summary of the ratios and graduated color quantities maps suggest that at least 33 percent of stations' ratios are below 0.8 for all demographic characteristics categories except for gender, which means that inequity of bikeshare system accessibility between exists. Language proficiency is the one that needs to address more focus on, which has 54 percent of stations' ratios are below 0.8. Second, after doing spatial autocorrelation analysis for each category of demographic characteristics, education level and income level are two categories are statistically significant, and education level's Moran's I is about 0.13, which indicates there is some degree of spatial autocorrelation existing. Based on the result of Getis-ord Gi, hotspots are in Evanston, Oak Park, Hyde Park, and South Side, while coldspot is clustered in Downtown Chicago.

Limitations

The empirical findings should be interpreted carefully. First, the demographic data is from 2016 American Community Survey 5-year file, which contains data from 2011 to 2016. Some data used in the analysis might not be recent data, which can cause errors when doing analysis for year 2016. Second, bike share stations are not equally distributed in the area. The higher the density of stations in one area, the more likely that same group of people will be double counted for multiple stations when intersecting station buffer layer and block group layer. The fact may lead to cluster effect which produce similar analysis results for stations that are close to each other, and cause bias in spatial autocorrelation analysis. Third, the minority groups are not officially defined, and different criteria can lead to different results. For example, "low-income" has

multiple ways to determine, some agencies use twice of the household poverty line, while some agencies use 60% of median household income in service area.

Recommendations

After conducting the various analyses described above, several recommendations have been come up to improve the equity of Bikeshare System accessibility evaluation process. First, a better range of buffer around stations need to be identified to lower the cluster effect caused by overlapping of multiple stations' buffer. Second, a more uniform definition of "low-income" is necessary to understand the true impacts of fare changes on these communities. The definition of low-income persons should be location-specific to take local income distributions into consideration. Third, local governments need to pay more attention to the importance of equity of Bikeshare System accessibility. An annual report of evaluation of the equity of Bikeshare System accessibility is highly recommended to be done by government agency or bike share operator as part of reference to ensure local transportation equity.

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